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Validation of improved laser Doppler anemometer (LDA) based on the fully developed turbulent round jet

Mohd Rusdy Yaacob[1*], Rasmus Korslund Schlander[2], Preben Buchhave[3], Clara Marika Velte[2]

[1)] Faculty of Electrical Engineering, Universiti Teknikal Malaysia Melaka,
Hang Tuah Jaya, 76100 Durian Tunggal, Melaka, Malaysia
[2)] Department of Mechanical Engineering, Technical University of Denmark, 2800 Kgs. Lyngby, Denmark
[3)] Intarsia Optics, Sønderskovvej 3, 3460 Birkerød, Denmark

[*]Corresponding e-mail: rusdy@utem.edu.my

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ABSTRACT – Accurate turbulence measurements are practically challenging even with common measurement techniques. The existing commercial LDA processors come with practical limitations affecting the measurement accuracy. A novel LDA has therefore been developed with utilization of recent technologies and state-of-the-art hardware and software, which enhance the capability of turbulence flow measurements. The software embedded offers an unlimited functionality for signal processing and data interpretation. Measurements were performed in the fully developed (equilibrium) region of a round jet at which the spatial turbulent kinetic energy spectra were found to perfectly match the expected Kolmogorov's -5/3 power law in the equilibrium region.

1. INTRODUCTION

Turbulence has long been a study which is yet to be completely defined and discovered especially in the developing (non-equilibrium) region [1]. Accumulating evidence point to that accurate investigations of flows in changing circumstances may very well lead to serious questioning of the established theory [2]. In order to realize this, it is of great interest to develop a novel, well-functioning Laser Doppler anemometry system that can measure turbulence under notoriously difficult conditions such as those at large radial distances from the centerline in a round turbulent jet (high turbulence intensities and high shear). LDA has earlier proven its significance as the primary choice, accurate and non-intrusive technique for turbulent flow measurements [3]. However, the current commercial LDA systems suffer from practical limitations, e.g., data buffering limitations and additional dead time due to data transfer [4]. By conducting the measurements using our self-developed LDA system in the fully developed jet, which has been thoroughly investigated and understood [5], the functionality of the system can be substantially validated upon comparison with the existing turbulence theory. From here, more rigorous measurements can later be performed in the non-equilibrium and high shear regions, which will present various degrees of difficulty for the LDA processor, with an ultimate aim, i.e., to test the important outstanding questions of turbulence, e.g., the universal equilibrium assumption.

2. METHODOLOGY

An axisymmetric turbulent round jet has been chosen as the test bed for the LDA measurement since it was proven to produce spectral results that are in good agreement with the Kolmogorov theory of turbulence in the fully developed region [6]. The jet is a replica from the one used by [7], with an exit diameter, *D* and contraction ratio of 10 mm and 3.2:1, respectively. The LDA was operated in burst-mode and 90º side-scattering detection configuration as in Figure 1. It consists of a continuous wave laser emitting a single beam with wavelength, λ = 532 nm, which is split into two coherent beams and passed through dual Bragg cells with 2 MHz effective frequency shift. This value is chosen based on the maximum Doppler frequency or velocity to be acquired from the measurement. The beams are then directed through a converging lens (focal point = 200 mm) and focused to intersect and create a measurement volume (MV), based on the dual-beam principle. Glycerin particles (1 to 5 μm) are seeded into the flow to pass through the MV. With the known fringe spacing, *df*, velocity can be determined using Equation (1):

$$\mathbf{u} = \frac{\lambda d_f}{2\sin(\theta/2)} \tag{1}$$

where θ is the angle between the two beams.

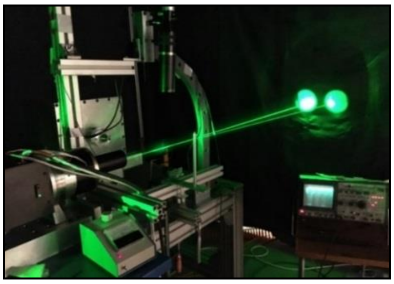

Figure 1 LDA system enclosed in a large tent

The block diagram for data acquisition of the LDA system is shown in Figure 2. The light scattered by each particle is received by a detector coupled to a photomultiplier which amplifies the photocurrent before passing through a low pass filter circuit. An electronic signal modulated by the frequency is then delivered to the oscilloscope and computer.

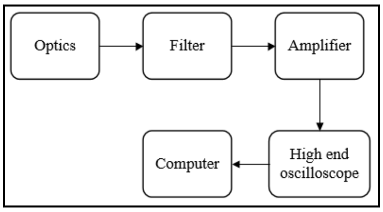

Figure 2 Data acquisition of the LDA system

Measurements were carried out along the radial, *r* direction at *x/D*=30 across the shear region as illustrated in Figure 3. The jet input pressure was set to 1 bar with an exit velocity around 40 m/s and the particles were fed into the flow at 1.2 bar. The laser was set nearly to its maximum intensity (1.29 W), with an amplifying current of 70 µA. A total of 400 records were taken at each measurement point with 2 s or 5 s record length, which corresponded to 25 MHz or 10 MHz sampling rate, respectively, optimized to the flow conditions at each measurement point. The output measured was transferred to a computer and processed using our self-developed software to obtain the spatial turbulent kinetic energy spectra employing the convection record method [8].

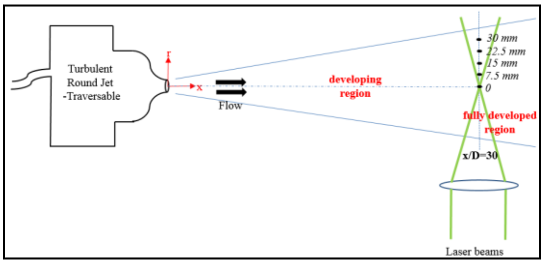

Figure 3 Distribution of the measurement points

3. RESULTS AND DISCUSSIONS

The shape of the kinetic energy spectrum is investigated in the fully developed region, i.e., at *x/D*=30 as in Figure 4.

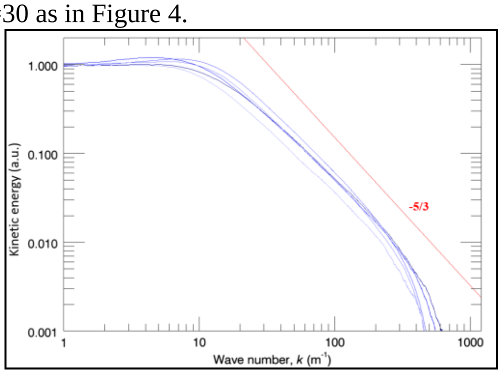

Figure 4 Radial development of spatial turbulent kinetic energy spectra at *x/D* = 30. From *heavy to light blue*: off-axis position 0, 7.5, 15, 22.5, 30 mm

The clear -5/3 slope across a significant range shows a good agreement with the -5/3 law for an (assumed) inertial subrange and the local equilibrium hypothesis postulated by Kolmogorov [9].

This behavior has also been previously supported experimentally using other measurement methods such as hot-wire anemometry [10] and stereoscopic Particle Image Velocimetry [11], which is clearly consistent with our results even at large radial distances from the centerline.

4. CONCLUSIONS

A high flexibility and accuracy novel LDA system has successfully been developed which provides the state-of-the-art tools; hardware in acquiring the data from measurement and software for data processing. The results obtained opens doors for further investigation to test the widely applied local equilibrium hypothesis for the structure of small scale turbulence.

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REFERENCES

[1] Kolmogorov, A. N. (1941). The local structure of turbulence in incompressible viscous fluid for very large Reynolds numbers. *C. R. Akad. Sci. SSSR 30*, 301.

[2] Vassilicos, J. C. (2015). Dissipation in Turbulent Flows. *Annu. Rev. Fluid Mech. 47*, 95–114.

[3] Buchhave, P., George, W. K. and Lumley, J. L. (1979). The measurement of turbulence with the laser-Doppler anemometer. *Annu. Rev. Fluid Mech. 11*, 443–503.

[4] Buchhave, P., Velte, C. M. and George, W. K. (2014). The effect of dead time on randomly sampled power spectral estimates. *Exp. Fluids 55(2)*, 1–8.

[5] Buchhave, P. and Velte, C. M. (2017). Conversion of Measured Turbulence Spectra from Temporal to Spatial Domain. In *Whither Turbulence and Big Data in the 21st Century?*, Springer, 343–362.

[6] Panchapakesan, N.R. and Lumley, J. L. (1993). Turbulence measurements in axisymmetric jets of air and helium . Part 1 . Air jet. *J. Fluid Mech. 246*, 197–223.

[7] Velte, C. M., George, W. K. and Buchhave, P. (2014). Estimation of burst-mode LDA power spectra. *Exp. Fluids 55(3)*, 1674.

[8] Buchhave, P. and Velte, C. M. (2017). Measurement of turbulent spatial structure and kinetic energy spectrum by exact temporal-to-spatial mapping. *Phys. Fluids 29(8)*.

[9] Batchelor, G. K. (1953). *The theory of homogeneous turbulence*. Cambridge University Press.

[10] Gibson, M. M. (1962). Spectra of turbulence in a round jet. *J. Fluid Mech. 15*, 161–173.

[11] Velte, C. M., Buchhave, P. and Hodzic, A. (2017). Measurement of turbulent kinetic energy spectrum - Part 2: Convection record measurements. *iTi Conference on Turbulence VII*, , 171–176.